

ECONOMIC EVALUATION OF FLEXIBLE PARTITIONS

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I wish to dedicate this thesis to my wife, Muna, and my two daughters, Ariella and Anneilee. I thank them for supporting and allowing me to sacrifice a lot of family time and other things so I could complete this research work.

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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF SYMBOLS AND ABBREVIATIONS	ix
SUMMARY	x
<u>CHAPTER</u>	
1 INTRODUCTION	1
2 BACKGROUND	3
Defining flexible wall partitions	3
Precedence studies	4
Building space flexibility from an architectural design perspective	7
Corporate real estate management and workspace flexibility	9
Traditional life cycle cost analysis, capital budgeting and flexibility in buildings	12
Problem statement	15
3 RESEARCH METHOD AND PROCESSES	17
Objective	17
Definitions of model boundary input parameters	17
Definitions of variable input parameters	19
Model assumptions	20
Decision-making structure for identification of uncertain variable	21
Creating cumulative risk profile for expected cost	24

Model development and representation	25
Overview of spreadsheet programming and Monte-Carlo simulation	33
4 CASE STUDY	34
Case study description and inputs	34
Case study results	37
5 DISCUSSION, CONCLUSION, AND RECOMMENDATIONS	45
Discussion and conclusion	45
Observations and recommendations	46
REFERENCES	47

LIST OF TABLES

	Page
Table 3.1: Model boundary input parameters	18
Table 3.2: Variable input parameters	20
Table 3.3: Sample α probability distribution	24
Table 3.4: Inputs for systems A and B	31

LIST OF FIGURES

	Page
Figure 3.1: Illustration of decision-making structure for creation of life cycle cost risk profiles of a partition in changing space layout conditions over three year	22
Figure 3.2: Illustration of a cumulative risk profile using values from Table 3.3	25
Figure 4.1: Illustration of scenario I of case study project	34
Figure 4.2: Illustration of scenario II of case study project	35
Figure 4.3: Illustration of scenario III of case study project	35
Figure 4.4: Illustration of α histograms for systems A	38
Figure 4.5: Illustration of α risk profiles for systems A showing mean, standard deviation, minimum and maximum values of the distribution	39
Figure 4.6: Illustration of α histograms for systems B	39
Figure 4.7: Illustration of α risk profiles for systems B showing mean, standard deviation, minimum and maximum values of the distribution	40
Figure 4.8: Illustration of α histograms for systems C	40
Figure 4.9: Illustration of α risk profiles for systems C showing mean, standard deviation, minimum and maximum values of the distribution	41
Figure 4.10: Superimposed α histograms for system A,B, and C	41
Figure 4.11: Superimposed α histograms for systems A,B, and C	41
Figure 4.12: Superimposed α histograms for systems A,B,C under sensitivity analysis	43
Figure 4.13: Superimposed α risk profiles for systems A,B, and C under sensitivity analysis	44

LIST OF SYMBOLS AND ABBREVIATIONS

α	Means path-specific cumulative cost
$E\alpha$	Means expected life cycle cost
ρ	Means range of probability values that can be used at chance nodes
n	Means project life span in years
f	Means frequency of switch or change scenario
μ_{α}	Means expected life cycle cost- same as $E\alpha$
q	Means constant probability value
S	Means number of space layouts
i	Means weighted average cost of capital
f	Means space rental rate
NS	Means no switch
DSM	Means design system matrix
WAAC	Means weighted average cost of capital
CDF	Means cumulative distribution function
IC	Means installation cost
OC	Means opportunity cost
MC	Means maintenance cost
RC	Means replacement cost
FC	Means first cost
IT	Means installation time
DA	Means decision analysis
DCF	Means discounted cash flows
LCC	Means life cycle cost

SUMMARY

Corporate Real Estate (CRE) investors are often confronted with a need for flexibility in buildings. They often embark on costly renovations to accommodate changing use requirements. When new needs arise, landlords and tenants often risk loss due to inability to easily switch to configurations that can meet those needs. The main cause for this problem is lack of a planning model that can allow buildings to easily evolve over time allowing decision-makers to hedge investment positions against risk due to uncertainty.

The emergence of Real Options (RO) theory in the 1970's has led to debates in search of a better planning model for real projects. The success of RO application in building construction (BC) hinges on the development of models that can be used to assess economic performance of flexible design options (FDO) in building systems. For building interior spaces, there is currently no model that can value flexibility of partition systems. The purpose of this study is to present a model that can be used to value flexibility in mutually exclusive partition systems over a project's life span. The proposed model uses decision tree representation, stochastic forecasting and random sampling of decision-path scenarios to generate cumulative risk profiles of partition systems' life cycle costs with expected median value, standard deviation and variance to inform decision making under uncertainty.

The research processes include: assumptions, decision-making structure for identification of uncertain variable, model representation, spreadsheet programming, Monte Carlo simulation, and validation. The model will enable application of RO "in" BC projects.

CHAPTER 1

INTRODUCTION

This paper proposes an economic valuation model that can be used to assess economic performance of flexible wall partition systems for building interiors under workspace demand uncertainty. The motivation that led to this study comes from the realization that constant change and uncertainty in CRE or BC projects are realities that have led to continuous investment of huge capital in renovation of rigid interior spaces to meet new-use requirements. In 2005, The Boston Consulting Group conducted a CRE benchmarking study in which 41 percent of real estate executives interviewed said that business unit projections of space demands are typically off by more than 100 percent (Apgar and Herkowitz, 2005). This highlights the reality that change is inevitable in the workplace due to forecasting errors.

The combination of forecasting errors and use of poor traditional planning models only lead to costly renovations throughout project life cycles. Historical data regarding these costs can be obtained from proprietary databases such as Reed construction data, HIS Global Insight construction data, McGraw Hill construction data, and from public databases such as the US Census Bureau (Value of Construction Put-in-Place expenditure reports and Annual Capital Expenditures Survey reports).

Although this study's focus is on valuation of partition systems, it has far reaching implications in BC in that it addresses a significant missing link in knowledge required to

solve the general problem of lack of flexibility in buildings which has vexed the industry throughout the history of building construction.

In order to sensitize the reader about the this topic, Chapter 2 addresses the following: definition of flexible partition systems and their significance in supporting a building asset's underlying purpose, precedence studies, building space flexibility from architecture and facilities design perspectives, CRE management and workspace flexibility, and deficiencies in traditional capital budgeting models. The discussion of these issues culminates in a summary problem statement for the research framework.

Chapter 3 presents the proposed model in the form of mathematical relations and illustrations. The proposed model is simply a risk profile of probable life cycle costs associated with use of mutually exclusive partition systems in a project. The model can be easily programmed into a spreadsheet and run with help of Monte Carlo simulation.

Chapter 4 uses a case study to validate the model by assessing the value of three partition systems that can be used in speculative project over a given period of time. The results of this case study, which are in the form of risk profiles, provide an opportunity to demonstrate a better methodology that can be used to inform the decision-making process in strategic design of workspaces. More specifically, the results demonstrate how the choice of a partition system for a project can impact not only the relative life cycle costs an organization may incur over a given project horizon but also how such early decisions can impact future management efficiencies and risk management.

Finally Chapter 5 discusses the research findings, conclusions and recommendations.

CHAPTER 2

BACKGROUND

Defining flexible wall partitions

In order to discuss economic evaluation of flexible partition systems, it is important to define what flexible systems are and how they matter in the context of workspace. According to the *Oxford dictionary of Architecture* (Curl, 1999), a partition is simply referred to as a non-load bearing wall where wall means a structure serving to enclose a room, a house or other space. In commercial buildings, especially corporate office buildings, interior partition systems are used to divide tenant spaces and various work spaces. This way, they support the purpose of the building's underlying asset, workspace, in generating rent income for landlords or to housing operations at minimal cost relative to income generated by the operations in the case of tenants. The extent to which partitions may be used to shape workspaces varies based on the decision-makers' preference on the basis of short term needs and strategic plans.

Partition systems are generally distinguished from furniture systems or cubicles in the sense that they are considered as building system components as opposed to furniture. In the United States, evidence of this distinction can be found in the classification used by construction cost data publications such as *RSMeans Interior Cost Data*. These publications do not include partition assemblies and systems furniture under the same product classification. Also, the specification format used by the Construction Specification Institute differentiates partitions from systems furniture by listing partitions

in a separate division (10) while keeping system furniture in a division (12) dedicated to furnishings. This is evidence of an industry consensus regarding the difference between partition systems and furniture systems.

In regards to the issue of flexibility in partitions, the term “flexible” is generally applied to partition systems that can provide the benefit of adapting to changing space layout more efficiently compared to standard partitions. This understanding is not far from the definition of flexible system used in engineering systems where a flexible system is defined as one that can be changed by an external agent as response to changing environment or internal state (Ross, 2008,Shah, Viscito, Wilds, Ross, and Hastings, 2008). There are different types of flexible partitions and they are differentiated by the way they adapt to changing space requirements and these include: operable or retractable, moveable or demountable, and in some cases folding partitions. The selection of a flexible partition is often based on project design criteria and functional analysis.

Precedence Studies

Documented use and costs analysis of flexible partition systems versus standard or permanent partition systems in the United States can be traced back to the late 1950s. In 1958 Federal Council Technical Report #33 was created by a study group (Task Group T30) under contract # 263 between National Academy of Sciences and National Bureau of Standards. The report was created from a study that was mandated to evaluate the total costs over a period of time (60 years) of two designs: one with conventional partition

systems and the other one using moveable-reusable partitions. The study was applied over a variety of building types that were limited to laboratories, offices and hospitals. It involved a survey of experiences from government agencies as well as private owners. The study was initiated in part because of experiences of inadequate preliminary estimates of original costs of moveable partitions versus permanent partitions and their effect on obtainable plan efficiencies or utilization factors. There was a feeling at the time that if facts, experiences and costs were clearly related to costs trends, then there could be a basis for reaching sound decisions in regards to preferential use of one system over the other.

The study involved survey questionnaires send to 36 federal agencies, eleven manufactures, and sixty-six owners. According to the report, responses were obtained from 28 agencies, four manufactures and sixteen owners. Analysis methodology employed by the task force group used life cycle cost analysis formulae derived from FCC Technical report #18- Selection of Windows, which is based on DCF capital budget model.

The results of the study indicated that while moveable partitions were more expensive than permanent partitions, they actually resulted in costs savings over a sixty year life of the building. All amounts were computed in present dollars.

Several significant recommendations and observations were made from the study. Two recommendations made were: First, the task group recommended that federal agencies

consider seriously the use of moveable partitions instead of the permanent types whenever the moveable systems can be expected to fill the need. According to the report, this recommendation was made on the basis that progress in technology and changes in staff may increase the obsolescence of plan arrangement so that increased flexibility in the assignment of space would be of great value in the passage of time; Second, the task group recommended that manufacturers of moveable partitions develop industry standards for their partitions to stimulate customer acceptance of their products, increase use volume and profits, and reduce prices.

Two observations were noted by the report. The first observation was that Manufacturers as a group could improve their services by being informed on comparative prices of all types of permanent partitions as well as prices of their own product. The second was that more facts were needed if owners were to make the best decisions. To support this, the study pointed out that many owners surveyed, stated that they had installed moveable partitions but in answering the survey questions it was obvious that price played a small part in shaping their decisions which appeared to have been based mostly on the belief that moveable partitions are fast to erect and relocate.

While this precedence study represented a significant undertaking by the federal government, it has several deficiencies. First it does not present a universal model that can be applied in project planning; instead it is just an analysis of gathered facts and recommendations. Secondly, the task group relied on use of linear LCC formulae to analyze implications of the cost information gathered through survey. Linear LCC is a

deterministic valuation methodology that does not factor risk due to uncertainty; a proper analysis should address this concern. Thirdly, the study failed to account for opportunity costs involved during downtime due to relocation of partitions, time is always of essence in building investments. While this study had its own contributions in provoking a debate on the matter, it underscores the gaps in knowledge required to create a universally accepted valuation model that can address all these stated deficiencies. The purpose of this study is to bridge these existing gaps of knowledge.

Building space flexibility from architecture and facilities design perspective

According to one of the world's leading architecture firms in the area of rate of change in building systems, DEGW, the unit of analysis for design of a building should be time (Brand, 1993). Time defines the real design problem (Brand, 1993). Rate of change theory views a building asset as being made of different systems or layers that have different rates of change over the building's life span. One of these systems is the space plan or layout (Brand, 1993, Duffy and Henney, 1989). According to independent surveys by Brand as well as Duffy and Henney, a space plan in a commercial building traditionally changes every five to seven years due to changing use requirements. In turbulent commercial markets space plan changes may occur every three years (Brand, 1993).

Analysis of historic data indicates that life cycle or cumulative capital costs associated with changes on space plan in a project can be many times the cost incurred at initial build-out (Duffy and Henney, 1989). According to the rate of change theory advocates, the historic evidence of constant change in buildings over time is a design mandate that requires buildings to be designed for change to meet the continuously changing end-use requirements. The huge cumulative costs associated with changes in buildings over time result from rigid buildings that are unable to evolve with time (Brand, 1993, Duffy and Henney, 1989). The rigid buildings themselves are a result of traditional planning models that fail to recognize the value of flexibility in buildings.

The rate of change theory arguments reveal weaknesses in both traditional capital budgeting and design. Traditional capital budgeting methodology uses the NPV model that employs linear DCF to represent cash flows in a project horizon and cannot value flexibility or manage risk due to uncertainty. Instead, it leads to a second problem: deterministic design approach. Designers are often pressured to meet given budgets for given project requirements (Duffy and Henney, 1989). The deterministic forecasts that are used to create project requirements lead to a compounded problem when presented with deterministic budgets. They constrain designers' ability to think outside the box since the budget and project requirements are both deterministic. In an effort to create value, the designer's best effort only culminates in use of linear life cycle cost analysis to choose between mutually exclusive building systems.

This study seeks to close the gap of knowledge required to meet the aspirations of the rate of change theory. In order to use time as the unit of design, designers should not only be encouraged to use flexible design options in projects but should also be equipped with a valuation methodology that can allow informed economic selection between mutually exclusive partition systems. The right valuation methodology must use probabilities and stochastic simulations to represent changing project conditions over a building's life cycle. Such a valuation methodology would encourage the industry towards adoption and application of capital budgeting models that value flexibility such as RO and will increase management of risk due to uncertainty in building construction and real estate investments.

Corporate Real Estate (CRE) Management and Workspace Flexibility

Many in CRE management are quickly becoming aware that the old ways of managing built assets will soon be a thing of the past. Current research by the Boston Consulting Group indicates that since IBM's turnaround in the 1990s, many savvy organizations have discovered that proactive management of CRE can unlock huge shareholder value while transforming the workplace and leveraging customer base (Apgar and Nomizu, 2005).

Traditional CRE management has been a straight forward exercise that simply required investors to identify good locations, negotiate long term leases and cut occupancy costs (Apgar and Herskowitz, 2006). But in recent years it appears that a variety of factors

have increased competitive pressure upon CRE executives causing them to reassess the viability and effectiveness of traditional models in CRE management. This has resulted in CRE executives becoming more agile in making leasing and design decisions while also getting increasingly shrewder in negotiating with developers for flexible, efficient, and user-friendly buildings (Apgar and Nomizu, 2005). It seems the overall objective behind all this effort is to shrink unnecessary occupancy costs so as to support better financial performance of an organization (Apgar and Herkowitz, 2006).

A careful assessment of the factors that have led to this competitive pressure and the subsequent re-shaping of CRE management can be traced to an increased pace of change in doing business. The two main distinct sources of change in corporate business or in the workplace (Hassanain, 2006, NCPP, 2004) can be summarized as follows:

- (1) External changes beyond the control of an organization such as technological changes, innovations, competition, globalization, regulation, de-regulation and consumer behavior.
- (2) Internal pressures from an organization such as initiatives and proposals.

While many diverse responses can be taken by CRE executives to manage their portfolios and support their business units for success, Apgar and Nomizu point out that the most important best practice in asset management is to segment real estate decisions so they reflect the fundamental differences among choices that are mandatory, periodic, cost saving, growth driven and strategic. Of these choices, it appears that strategic decisions

such as adding unanticipated locations and performing major retrofits, as pointed out by Apgar and Nomizu, would have a greater impact on managing risk due to uncertainty by allowing embedment of flexibility on workplace configurations. Apgar and Nomizu have proposed Growth Strategy Alignment (GSA) as the most effective means to make strategic choices in CRE management.

According to Apgar and Nomizu, GSA is a two-stage process that requires CRE departments to: first understand the range of possibilities defined or implied in business plans; and second, translate each growth scenario into projected space requirements. Once those two requirements are satisfied, an organization can then match its current and projected portfolios against the spectrum of possibilities to identify short-ages, surplus, and key decision points such as lease renewals, extensions, and expansions (Apgar and Nomizu, 2005). The objective of the strategy is to fashion a portfolio that can accommodate growth and still be flexible enough to absorb downside scenarios with an understanding that ensuring future flexibility often means investing at the present time (Apgar and Nomizu, 2005).

The GSA is arguable a very credible proposition in managing risk due to uncertainty and is based on principles that transcend disciplines. The strategy has a fundamental commonality with principles of Real Options analysis, a capital budgeting approach that values flexibility. RO is currently being debated in systems engineering as well as in building construction / Real estate and is discussed in the next section of this chapter. However, what is important to note here is that RO application requires existence of a

valuation methodology that can be used to compare the spectrum of future costs of space configurations associated with all possible future scenarios. This study framework is intended to bridge such gap in knowledge to make GSA a practical possibility.

Traditional Life Cycle Cost Analysis, Capital Budgeting and Flexibility in Buildings

All building systems, including wall partitions, are traditionally valued using linear life cycle cost (LCC) analysis. Linear LCC analysis is an economic valuation process that uses Discounted Cash Flows (DCF) to determine NPV costs of building systems or components over the life of a project. In order to analyze the ability of linear LCC in addressing issues of flexibility, one has to understand the DCF budgeting approach.

The DCF capital budgeting approach is a method that uses the concepts of time value of money by estimating and discounting all future cash flows to net present value (NPV) (Greden, 2005, Geltner and Miller, 2001). The discount rate used is generally the weighted average cost of capital (WACC) which reflects the risk of the cash flows in two ways: the time value of money and the risk premium rate. The time value of money dictates that lenders would rather have cash now than having to wait so they are compensated by paying for delays. Risk premium rate reflects the extra return a lender demands in case the cash flow might not materialize after all. Basically, risk is addressed through a combination of a discount rate and a premium interest rate by forecasting the expected future flows, ascertaining the required total rate of return and discounting the cash flows to the present value at the required rate of return (Greden, 2005).

The DCF has several limitations. First it depends on one set of deterministic forecasts for both cash flows and project conditions. While it can be argued that it accounts for all permutations within the set of forecast employed, the problem is that there is no feedback regarding any single attribute (Greden 2005). Secondly, deterministic forecast are always wrong (Tao) as project conditions used in making initial budget decisions never stay the same throughout the entire life span of the project. In fact they change more frequently. This is simply a fundamental flaw in the model. Lastly, the process is irreversible and if future conditions turn out to be negative or create more opportunities than anticipated, nothing can be done within the process to alter cash flows. A single DCF calculation does not include the ability to value a project decision at a future point in time (Greden 2005).

Since linear LCC of a building system, inclusive of partitions, is a representation of DCF's associated with initial, maintenance and replacement costs of the system in a project, it exhibits the fundamental deficiency of the model, namely, inability to manage risk due to uncertainty. This deficiency can only be cured by re-assessing the valuation methodology using stochastic forecasts and a spectrum of probabilities instead of deterministic forecasts. The objective of this study is to close this gap in knowledge.

Another capital budgeting model that is available for use in valuation of building systems including partition systems is the Decision Analysis (DA) model. It is a method of project valuation that leads to three results (Greden, 2005) (de Neufville, 1990): Structuring of a complex problem, definition of the optimal choice for any time period based on joint

considerations of the probabilities and nature of outcomes , and identification of maximum strategy over many periods. While this method considers risk due to uncertainty in approach, its main draw-back is that it reduces full probability outcomes and distributions to discrete outcomes based on perceived maximum strategy. If the spread of the uncertain variable, in this case LCC, is very wide, it could lead to undesired results. There is a need to explore a better way that can present results in a full risk profile to enable decision makers to compare results based on mutually exclusive choices. This study proposes to close this gap in knowledge.

Real Options Analysis (ROA) is perhaps the most advanced capital budgeting methodology known to the building construction industry and other related disciplines. Practical applications based on this model are currently the subject of debate in various fields of study with a more rigorous discussion in systems engineering. Real Options theory is analogous to Options theory used in pricing legal financial “call” and “put” options and it is applied to a project during the planning phase. It can be applied “on” a project or “in” a project. When analysis is “on” the project it means that the option is external to the physical project. When used “in” the project it means the option is applied to the physical design. (Shah, Wilds, Viscito, Ross, and Hastings, 2008).

When using ROA “in” a project as would be the case with flexible partition systems or other building systems, the idea is to build a certain level of flexibility in the design of a project at a predetermined cost, option value, to create an opportunity to alter the project at a certain cost in the future, exercise value, in an effort to manage risk due to

uncertainty. In short, a real option gives the decision maker the right, but not the obligation, to exercise flexibility options at different times in the future when market forces or future conditions create a necessity or an opportunity. Flexible partitions systems can be used in application of ROA. However, the main problem is that ROA requires a model that can identify or select flexibility options by screening them before they can be embedded in the project. In the case of ROA application “in” interior design projects, this simply means there is still a need for a model that can value flexible wall partitions to select the best option for ROA application. The objective of this study is to close this gap in knowledge.

Problem Statement

Building spaces require to be designed with flexible options so they can easily evolve over time at the minimum cost possible to allow CRE investors to manage risk due to uncertainty. In order for building spaces to evolve easily and at a minimum cost possible, there must be a method that can appropriately enable cost assessment of candidate partition system to identify the best options for project implementation. Such a method can help competent proposal such as the Growth Strategy Alignment in CRE management to materialize. The method should do so by allowing predetermination of future costs of renovations associated with a choice of a flexible partition system at present time. It also must use stochastic analysis of future project conditions to assess probable costs based on probable turn of future events. Finally, it must enable time to be a workable unit of analysis in building design or architecture.

It is clear that the traditional life cycle costing methodology, and the DCF budgeting model from which it is derived, fail to satisfy all conditions discussed above. They cannot be used to value flexibility and help decision-makers hedge positions to minimize risk due to uncertainty. This paper proposes a research methodology and processes that will provide an alternative to linear LCC and bridge the gap of knowledge required to implement RO applications in design of flexible spaces.

CHAPTER 3

RESEARCH METHODOLOGY AND PROCESSES

Objective

The objective of this study is to propose a model that can be used to conduct an economic analysis or evaluation of mutually exclusive partition systems for a building interior space over a project's life span. The proposed model uses decision tree representation, stochastic forecasting and random sampling of decision-path scenarios to generate a cumulative risk profile of a system's life cycle costs whose expected value and standard deviation can inform decision-making under uncertainty. The research processes include:

1. Input data definitions and model assumptions
2. Decision-making structure for identification of uncertain variable
3. Model representation
4. Spreadsheet programming and Monte-Carlo simulation

Definitions of Model Boundary Input Parameters

Prior to composition and development of the proposed model, an analysis was conducted to determine the factors that would be required in the life cycle cost assessment of partitions and two set of inputs were identified.

The inputs in the first set were identified as necessary to control the comparative study process. In other words, these input parameters are factors that constitute the model boundaries. Although they may be varied from project to project, they must remain constant in a specific project evaluation. The following table contains a list of these inputs and it is followed by a brief explanation regarding the importance of each factor.

Table 3.1: Model boundary input parameters

Model Boundary Input Parameters		
Symbol	Description	Assumed unit of measure
n	Project life span	years
f	Frequency of change	years
i .	Weighted average cost of capital (discount rate)	percentage
\int .	Space lease/ rental rate	Currency per square feet per . lease time
ρ .	Risk definitions or range of probabilities representing forecasts	Probability ratio

Project Life Span - n

Credible economic valuation of partition systems should be considered within the context of a project's life span and in consideration of how often the building space layout changes within that span. For this study, project life span will be considered to be synonymous with building life span.

Frequency of change- f

It is important to analyze the economic performance of flexible partition systems on the basis of the frequency at which the space layout may change within the project life. It is

assumed that this frequency will be determined from forecasts created by the decision-making team.

Discount rate- i

In consideration of the cost of capital in financing construction, this study has determined that the economic valuation of flexible partition systems must use the weighted average cost of capital (WACC) for discounting. The exact value of the discount rate is left to the decision-maker.

Space Lease/ Rental- r

Space rental rates represent the most appropriate form to evaluate opportunity cost in real estate investments since they represent the income, the express purpose of the underlying asset. In carrying out economic analysis of mutually exclusive partition systems, space lease/ rental rates must be used in conjunction with the discount rate to evaluate opportunity costs.

Risk definitions or probabilities associated with project conditions- p

This data is developed during forecasting of project conditions and its purpose is explained in detail in the section entitled decision-making structure for identification of uncertain variable.

Definitions of Variable Input Parameters

The second set of inputs identified as necessary for the study represent system-specific variables required for an objective comparative analysis of the alternatives' economic performance under constraints of the model boundary. In other words these inputs represent the properties that make the difference in systems economic performance in a project. These inputs are represented in the table below are self explanatory.

Table 3.2: Variable input parameters

Variable Input Parameters		
Symbol	Description	Assumed Unit of Measure
ϕ	Labor Output/ Productivity rate	hours per linear feet
χ	Labor unit costs	cost per linear foot
Υ	Material unit costs	cost per linear foot
Pr .	Percentage of material re-usable during a switch or scenario change	percentage
μ	System unit maintenance costs	cost per linear foot
Θ	System maintenance period	years
k	System life span or useful life period	years

Model Assumptions

This study assumes that pre-screening of partitions systems can be conducted prior to the economic valuation process to ensure that all other project function requirements can be met. Function analysis is the most effective screening method that is recognized by the building construction industry. It is commonly used in traditional value engineering methodology and is appropriate to ensure that candidate partition system would meet project design criteria.

It is also assumed that stochastic forecasts and associated probabilities can be prepared with help of an analyst. Once forecasts are available, it should be relatively easy for designers to generate design scenarios for the model. The study assumes that design

scenarios will use the same partition heights since the scenarios will occur within the same space.

Additional assumptions are as follows:

- Excel spreadsheet programming and use Monte-Carlo simulation is relatively common
- WACC rate (i %) is to be determined by the decision-maker.
- Opportunity costs will be evaluated on the basis of eight (8) working hours per business day.
- Decision-makers have the ability to provide stochastic forecasting of their project conditions and determine appropriate range of probabilities associated with each project scenario. For the purpose of the study, project scenarios are represented through associated schematic design plans. From each schematic plan, the model user must measure the total length of all proposed new walls for input in the model. Ultimately the purpose of stochastic forecasting in the proposed model is simply to produce a length measure for new wall installation and an associated probability of occurrence of such a project condition.

Decision-making structure for identification of uncertain variable

In order to illustrate the basic decision-making structure that is necessary to appreciate the problem of uncertainty in the life cycle of a building's space layout, a basic decision tree can be used to layout possible paths of change that a space layout may experience after initial build-out. These possibilities must be based on stochastic forecasts that consider the impact of possible change on project conditions and associated space layouts. Figure 1 below illustrates how a space may change from an initial layout (I) to

future layouts (II and III) in a project life span that accommodates three switches. The figure also illustrates that a no-switch (NS) branch must be included as a possibility when analyzing probable changes.

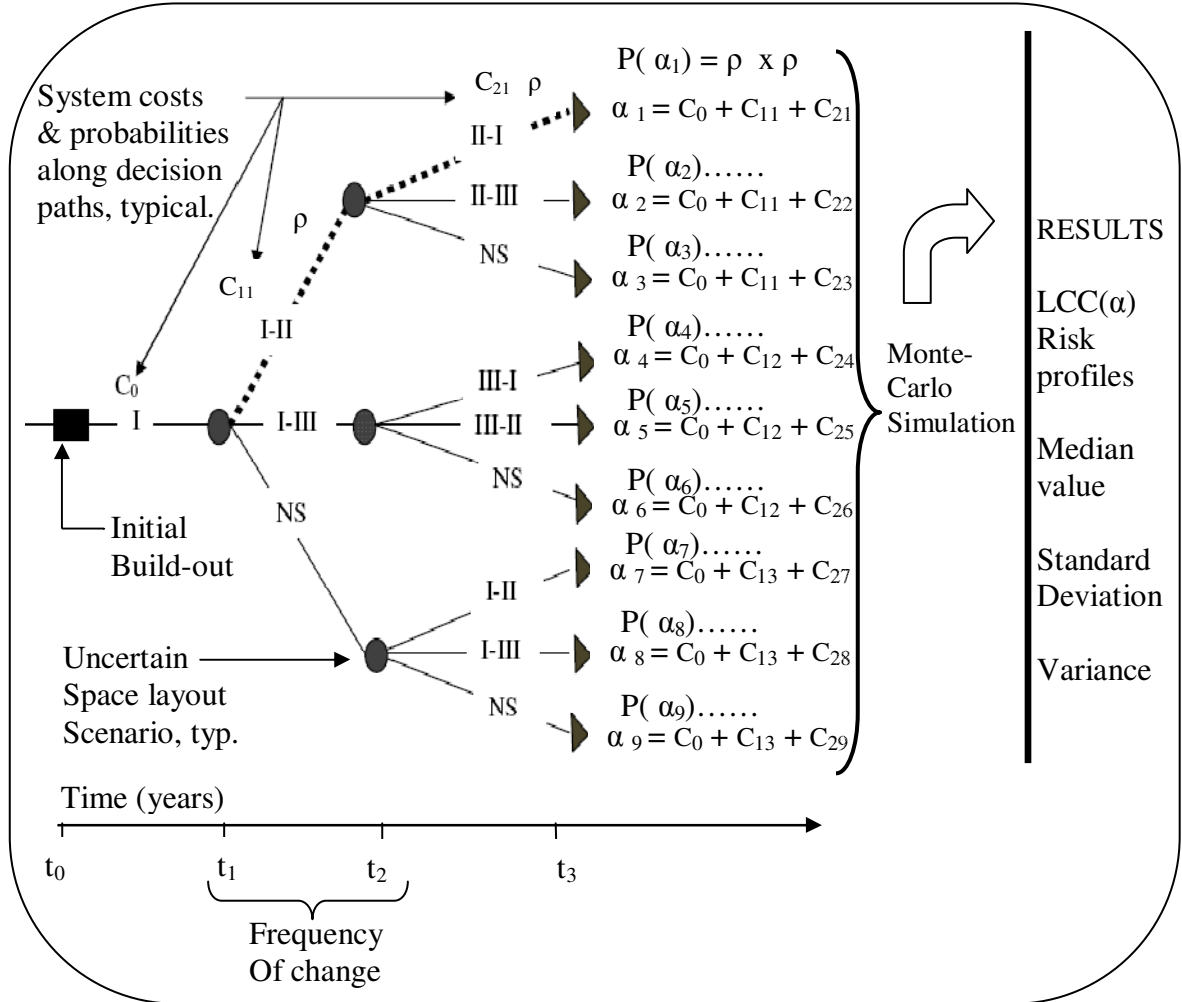


Figure 3.1: Illustration of decision-making structure for creation of life cycle cost risk profiles of a partition system used in changing layout conditions over three years.

In analysis of decision tree representations such as in figure 3.1, the number of all possible switch types at chance nodes for any given set of possible future design

scenarios in a project's life is equal to the square of the number of all such scenarios or design layouts, see equation below.

$$\eta = S^2 \quad \text{Equation 1}$$

Where:

- η represent the number of possible change scenarios
- S number of space layouts or design scenarios

As illustrated in Figure 1, costs associated with use of a flexible partition system can be traced, appropriately discounted, and added along the respective decision path to determine the system's cumulative cost at the end of the project along the path. If this process is followed for all possible paths, then a range of path-specific cumulative cost (α) values can be determined for the system. These values and their probability of occurrence can be used to create a mass function that can be displayed in a graphical form such as a histogram. The values can also be used to create a cumulative distribution function (CDF) which can be in the form of a cumulative risk profile.

A cumulative risk profile is a continuous graph that a decision maker can use to determine the likelihood of expected cost being at a given value or less during analysis of risk (Clemen, R.T and Reilly, T., 2001). Individual risk profiles generated for each alternative system can be compared using the concept of stochastic dominance to determine which alternative is most attractive in terms of probable life cycle costs. In other words, this study suggests that in order to provide objective comparison of economic performances of alternative partition systems in evolving project conditions, it is necessary to generate risk profiles of the uncertain variable α for each system. The

weighted-probability function of α values for a system is equivalent to the expected value ($E\alpha$) which represents the mean of the system' cumulative risk profile. Both $E\alpha$ and the spread of a system's α distribution can lead to different levels of confidence in selecting a system.

Creating cumulative risk profile for expected cost

The process of creating cumulative risk profile using α values attributable to a particular system in a project is a fairly simple one. Once α values are known, the probability of their occurrence can be determined by computing the product of probabilities from sequential branches along the respective path. The risk profile is then graphed by plotting the cumulative probability values against α values. The largest α value is plotted against the sum of its probability and all the probabilities for the lower values. The process is repeated in decreasing order. All plotted points are then connected such that the probability of any α value is represented as cumulative of all probabilities of lower and equal values. Table 1 and Figure 3.2 below show how a cumulative risk profile can be created using α values and probabilities.

Table 3.3: Sample α probability distribution

α value	Probability
\$3000	0.20
\$3500	0.20
\$4000	0.20
\$4500	0.20
\$5500	0.20

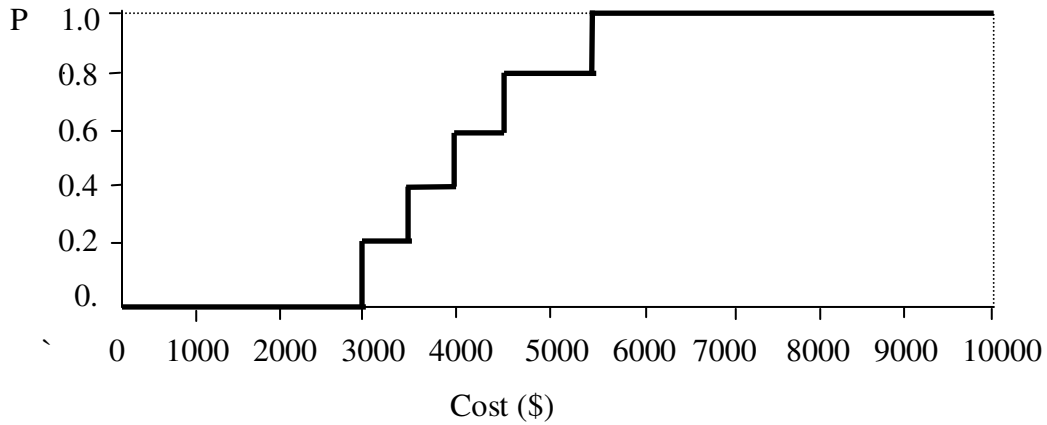


Figure 3.2: Illustration of a Cumulative Risk Profile using values from Table 1.

Model development and representation

As already explained, this study views project life cycle costs attributable to use of a partition system only as probable and not definite. This is in contrast to the deterministic position in traditional life cycle cost analysis. As illustrated in Figure 3.1, there is always more than one possible α value for a project in consideration of uncertainty. Thus α is the uncertain variable in this analysis and is the focus of modeling. α can be represented as the sum of the first costs and all subsequent costs attributable to use of a partition system along a specific change-scenario or decision path and can be best represented by the following equation:

$$\alpha = FC + \sum_{j=1}^n C_j (P/C_j, i\%, j) \quad \text{Equation 2}$$

Where:

- $C_j = IC_j + OC_j + MC_j + RC_j$ Equation 3

- $FC = IC_0 + OC_0$ Equation 4

- n is the project's life span in years,
- i is the WACC rate
- FC is first costs
- IC is system installation cost
- OC is system opportunity cost
- MC is system maintenance cost
- RC is system replacement costs.

Please note that computations of FC, IC, OC, MC and RC are discussed in more details later in this section.

Once α values have been determined in accordance with equation 2 above, they can either be used to create a mass function that can be represented in a histogram for risk analysis or they can be used to create a cumulative risk profile. In either case, probability of occurrence for each α value is required to create either risk profile. The probability of selecting a path ending with a specific cumulative cost value is equal to the product of sequential probabilities at chance nodes along the path.

$$P(\alpha) = \prod_{h=0}^{n/f} \rho_h \quad \text{Equation 5}$$

Where

- ρ represent a range of probability values that can be used at chance nodes
- n represents the project life span in years
- f represent the anticipated frequency of switch or change scenario in years

If constant probability is used at sequential nodes then equation 5 can be re-written as:

$$P(\alpha) = \rho^{n/f} \quad \text{Equation 6}$$

Where

- σ is the value of constant probability.

Now, since the uncertain variable α has been defined using equation 2 and its probability of occurrence has been defined using equation 5 and 6, a probability-weighted average representing expected cost can be determined using the expected value relation. That is, the mean of the cumulative risk profile, $E(\alpha)$, can be defined as a probability function of α and can be represented as follows:

$$\begin{aligned} \mu_\alpha &= E(\alpha) \\ &= FC + E(\alpha) \\ &= FC + \left(\prod_{h=0}^{n/f} \rho_h \right) (\{ \sum_{j=1}^n C_j (P/C_j, i\%, j) \}_1 + \{ \sum_{j=1}^n C_j [P/C_j, i\%, j] \}_2 + \dots \\ &\dots + \{ \sum_{j=1}^n C_j [P/C_j, i\%, j]_m \}) \end{aligned}$$

The relation can be reduced to:

$$\begin{aligned}\mu_\alpha &= E(\alpha) = FC + E(\alpha) \\ &= FC + \left(\prod_{h=0}^{n/f} \rho_h \right) \left(\sum_{k=1}^m \left(\sum_{j=1}^n C_j [P/C_j, i\%, j] \right)_k \right)\end{aligned}\quad \text{Equation 7}$$

If constant probability is used as illustrated in equation 6, then equation 7 can be re-written as follows:

$$\begin{aligned}\mu_\alpha &= E(\alpha) = FC + E(\alpha) \\ &= FC + \rho^{n/f} \left(\left\{ \sum_{j=1}^n C_j (P/C_j, i\%, j) \right\}_1 + \left\{ \sum_{j=1}^n C_j [P/C_j, i\%, j] \right\}_2 + \right. \\ &\quad \left. \dots\dots\dots + \left\{ \sum_{j=1}^n C_j [P/C_j, i\%, j]_m \right\} \right)\end{aligned}$$

and reduced to:

$$\mu_\alpha = E(\alpha) = FC + \rho^{(n/f)} \sum_{k=1}^m \left(\sum_{j=1}^n C_j [P/C_j, i\%, j] \right)_k \quad \text{Equation 8}$$

Two other useful measures that can help determine the spread of the probability distribution for the uncertain path-specific distribution cost is the variance, represented using standard mathematical notation $\text{Var}(\alpha)$ or (σ_α^2) , and the standard deviation (σ_α) of uncertain variable cost. The full expression of the variance of the cumulative cost of a system can be represented follows:

$$\begin{aligned}\sigma_\alpha^2 &= [\alpha_1 - \mu_\alpha]^2 P(\alpha = \alpha_1) + [\alpha_2 - \mu_\alpha]^2 P(\alpha = \alpha_2) + \dots\dots\dots + [\alpha_m - \mu_\alpha]^2 P(\alpha = \alpha_m) \\ &= \sum_{k=1}^m [\alpha_k - \mu_\alpha]^2 P(\alpha = \alpha_k) \\ &= E[\alpha - \mu_\alpha]^2\end{aligned}\quad \text{Equation 9}$$

The standard deviation is simply the square root of the variance (Clemen, R.T and Reilly, T., 2001) and in this case it can be represented as follows:

$$(\sigma_{\alpha}) = E[\alpha - \mu_{\alpha}] \quad \text{Equation 10}$$

Equation 2, 3 and 4 above require computations involving one or more of the following variables: IC, OC, MC and RC. The following is a list of relations that show how to compute these variables using input information obtained through a combination of expert advice, cost data publications, and manufacturer publications:

Equation 11

$$IC = (\Upsilon + \chi) \times L + \text{Other costs adjustments}$$

Equation 12

$$OC = [IT - IT \text{ of faster system}] \text{ hrs} \times 1 \text{ day} / 8 \text{ hours} \times f \times A$$

$$IT = L \times \phi. \quad \text{Equation 13}$$

Where:

- Υ means material unit cost
- χ means labor unit cost
- L means length of proposed wall installation
- A means leasable area that will be impacted by construction
- ϕ means labor output or productivity rate
- f means space lease/ rental rate

Equation 12 uses a factor of one day per eight hours to convert the difference in installation time to leasable days that can be easily used to determine how much rent is lost during business down-time due to construction activities. See example 1 later in this section.

$$MC = M \times L \quad \text{Equation 14}$$

$$RC = \text{Material cost} \times \text{Length of wall being replaced.} \quad \text{Equation 15}$$

It is important to note that installation costs and opportunity costs (equations 11 and 12) can be used to compute first costs at the beginning of a project as well as switch costs at chance nodes using the appropriate equations as explained in the model representation. However, replacement and maintenance costs (equations 14 and 15) need to be calculated along the path in accordance with the period and frequency requirements of the systems manufacturer. The following computation example is an illustration of how node level computations would be carried out:

Example 1: Compare total discounted costs associated with use of two mutually exclusive partition systems A and B for a relocation of a 10 feet long wall. The work is likely to occur at the beginning of the ninth year from the date the project was built. Assume the following: WACC (i) as 8%, frequency (f) of switch as 3 years, lease rate(f) as \$20 per square feet annually. Leasable area (A) affected is 3000 square feet. The properties of system A and B are given in the following table.

Table 3.4: Inputs for systems A and B

System	ϕ	Υ	χ	Pr
A	1 hr/l.f.	\$10/l.f.	\$30/l.f.	0%
B	0.3 hr/l.f.	\$123/l.f.	\$100	90%

Answer:

System A

$$IC = (\Upsilon + \chi) \times L$$

$$= (\$10/\text{l.f.} + \$30/\text{l.f.}) \times 10 \text{ feet}$$

$$= \$3000$$

$$IT \text{ (required to compute OC)} = \phi L$$

$$= 1 \text{ hr/ l.f.} \times 10 \text{ feet}$$

$$= 10 \text{ hrs}$$

$$OC = (IT - IT \text{ of B}) \text{hrs} \times 1 \text{ day}/8\text{hrs} \times f \times A$$

$$= (10 \text{ hrs} - 3\text{hrs}) \times (1\text{day}/8 \text{ hrs}) \times \$20 / (\text{s.f.} \times 366 \text{ days}) \times 3000 \text{ s.f.}$$

$$= \$143$$

$$\text{Total costs} = IC + OC$$

$$= \$3000 + \$143$$

$$= \$3143$$

Total discounted costs = \$3143 (P/F, 8%, 9)

$$= \$3143 \times 0.5002$$

$$= \$1572$$

System B

$$IC = (\gamma + \chi) \times L$$

$$= (10\% \times \$123/\text{l.f.}) \times 10 \text{ feet} + \$10/\text{l.f.} \times 10 \text{ feet}$$

$$= \$123 + \$100$$

$$= \$223$$

$$IT = \phi L$$

$$= 0.3\text{hr/l.f.} \times 10 \text{ feet} = 3 \text{ hrs}$$

OC = 0 since this system is faster than system A and does not cost the investor any opportunity in comparison to system A

Total discounted costs = \$223 (P/F, 8%, 9)

$$= \$223 \times 0.5002$$

$$= \$112$$

Costs for system B is less than that of system A for at this particular node.

Summary

For project conditions represented by S (see equation 1) interior space layouts or design scenarios or η (see equation 1) scenario paths, create a risk profile of probable life cycle costs associated with use of each candidate partition systems using equation 2 through 6 and equations 11 through 15. Then compare the spreads and risk implications of each risk profile to inform decision making. Expected life cycle cost, Variance and Standard deviations of each risk profile can be computed directly using equations 6 through 10.

Overview of Spreadsheet programming and Monte Carlo Simulation

The model represented in this study can be easily programmed into a spreadsheet and run with help of Monte Carlo simulation. Multiple scenarios of the model can be created in different spreadsheets to create different project horizons and other custom settings that can allow for analysis of multiple projects. Programming algorithms in Microsoft excel can be created using a combination of the model equations, IF, AND, and OR functions to achieve desired programming objectives. As already mentioned before, the study assumes that spreadsheet programming and use of Monte Carlo is common knowledge and as such full illustration of the model spreadsheet is omitted in this presentation.

CHAPTER 4

CASE STUDY

The presented model was tested using a case study to measure the value of three mutually exclusive partition systems in a speculative interior space project.

Case study description and inputs

Scenario descriptions

Three varying floor plans within the same foot print were used to represent three possible design scenarios over a span of 30 years. The first layout, considered the base scenario or scenario I had an overall length of wall partition that measured 136 feet. The second layout, scenario II, had an overall length of wall partition that measured 72 feet. The last and third layout, scenario III, had an overall length of wall partition that measured 119 feet. See figure 4.1 below for the design scenarios or layouts. Nine feet (9ft) height was assumed for all scenarios throughout the project life.

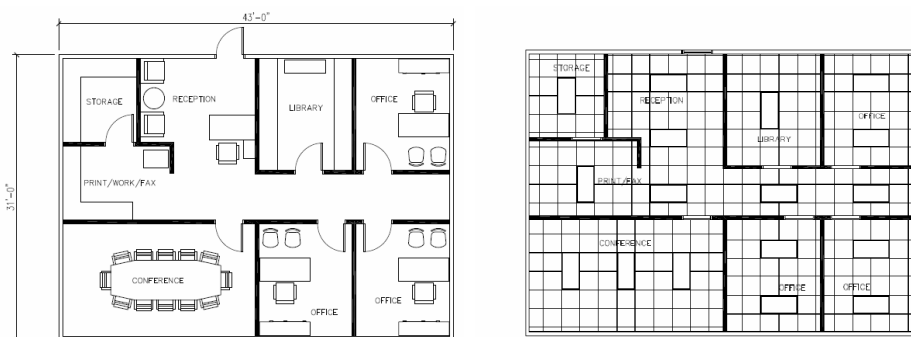


Figure 4.1 Illustration of Scenario I of case study project.

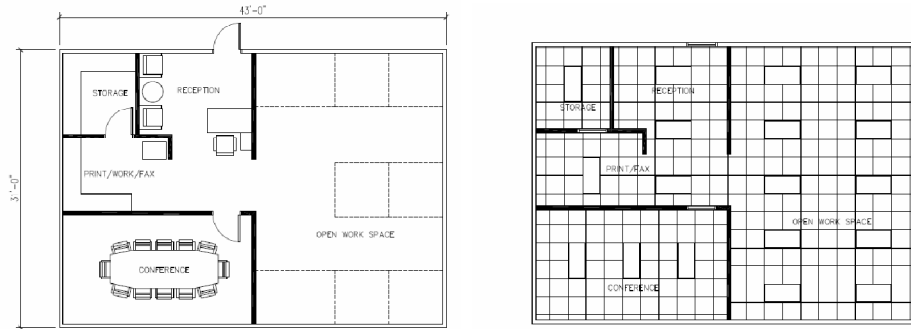


Figure 4.2 Illustration of Scenario II of case study project.

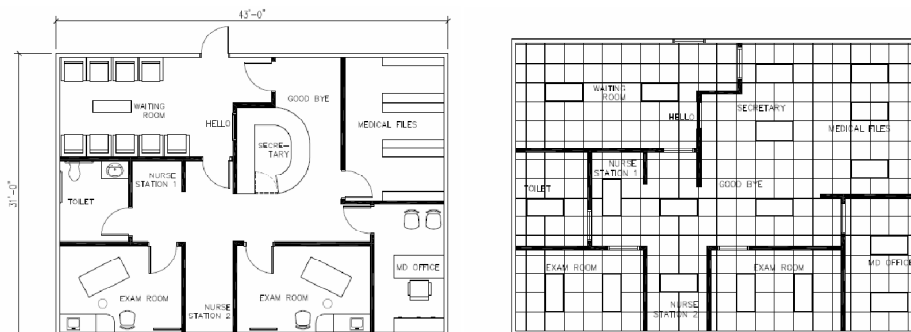


Figure 4.3 Illustration of Scenario III of case study project.

Project parameters

- Project life span- 30 years
- WACC rate - 8%
- Regular anticipated frequency of switch- 3 years
- Lease rate - \$20 per square feet per annum
- Area (all leasable) – 1333 square feet for all scenarios

System properties.

Information about the three partition systems used was gathered from RSMeans Interior Cost Data, 26th Annual Edition. The systems chosen included a gypsum wall board

assembly designated system A and two other systems classified as flexible designated B and C.

Properties of system A were as follows:

- Labor output- 1 hr per linear feet
- Material costs- \$12.24 per linear feet (after conversion from cost per square feet)
- Percentage of material reusable during a switch- 0%
- Labor costs- \$27.9 per linear feet
- Maintenance costs- \$5.04 per linear feet
- Cycle period for required maintenance- 6 years
- System's life span- 30 years
- Salvage value- \$0 assumed
- Replacement costs- assumed same as new

Properties of system B were as follows:

- Labor output- 0.333 hrs per linear feet
- Material costs- \$56 per linear feet (after conversion from cost per square feet)
- Percentage of material reusable during a switch- 100%
- Labor costs- \$13.3 per linear feet
- Maintenance costs- \$0 per linear feet
- Cycle period for required maintenance- Not applicable
- System's life span- 15 years
- Salvage value- \$0 assumed
- Replacement costs assumed same as new.

Properties of system C were as follows:

- Labor output- 0.267 hr per linear feet
- Material costs- \$138 per linear feet (after conversion from cost per square feet)
- Percentage of material reusable during a switch- 100%
- Labor costs- \$10.65 per linear feet
- Maintenance costs- \$0 per linear feet
- Cycle period for required maintenance- Not applicable
- System's life span- 15 years
- Salvage value- \$0 assumed
- Replacement costs- Assumed to be same as new installation costs.

A spreadsheet program aided by @Risk software add-on was used to carry out the stochastic simulations involving all three partitions using the same project conditions. Ten thousands iterations of were conducted using the Monte-Carlo simulations. The results were displayed in both a probability distribution histogram and a cumulative risk profile. The graphs for the three systems were superimposed for analytic comparison of their expected costs.

Case study results.

Figures 4.4 to 4.9 below show LCC histograms and their associated cumulative risk profiles for the three systems. Figure 4.10 and 4.11 show the superimposed histograms

and risk profiles respectively. Observation of the superimposed risk profiles show that system C stochastically dominates both system A and B as its graph lies to the right of the others. This stochastic dominance is in terms of cost which means systems A and B will be preferred to system A. On the other hand, there is no stochastic dominance between system A and B as their graphs cross each other and have close spreads. Their expected costs or mean values are only separated by a mere \$534 and a decision cannot be made to choose between the two except through sensitivity analysis. See sensitivity analysis and results in the next section.

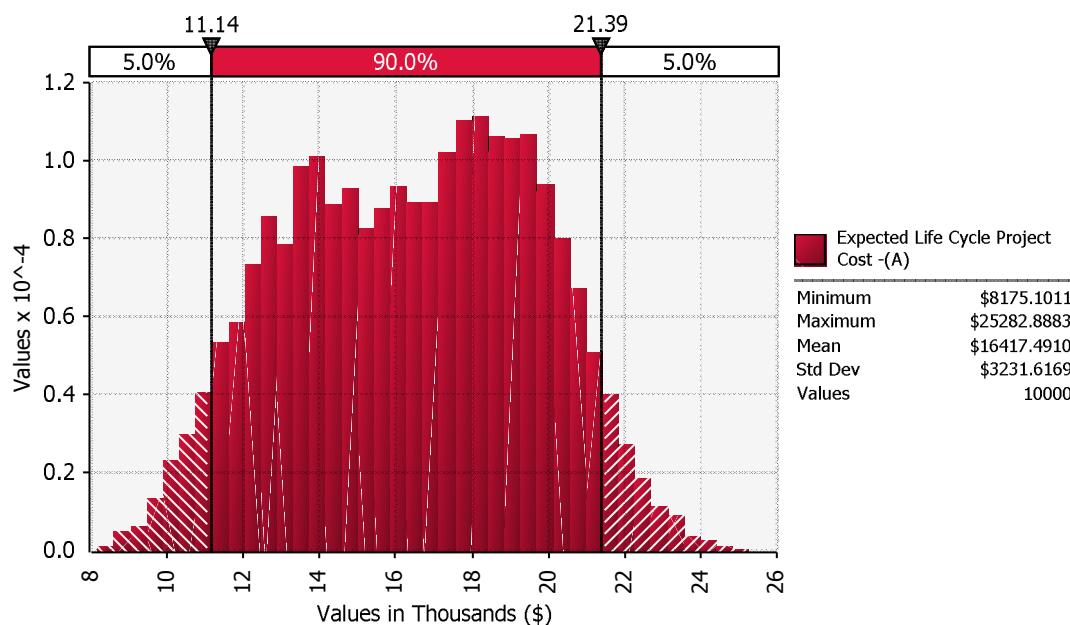


Figure 4. 4: Illustration of α histogram for system A

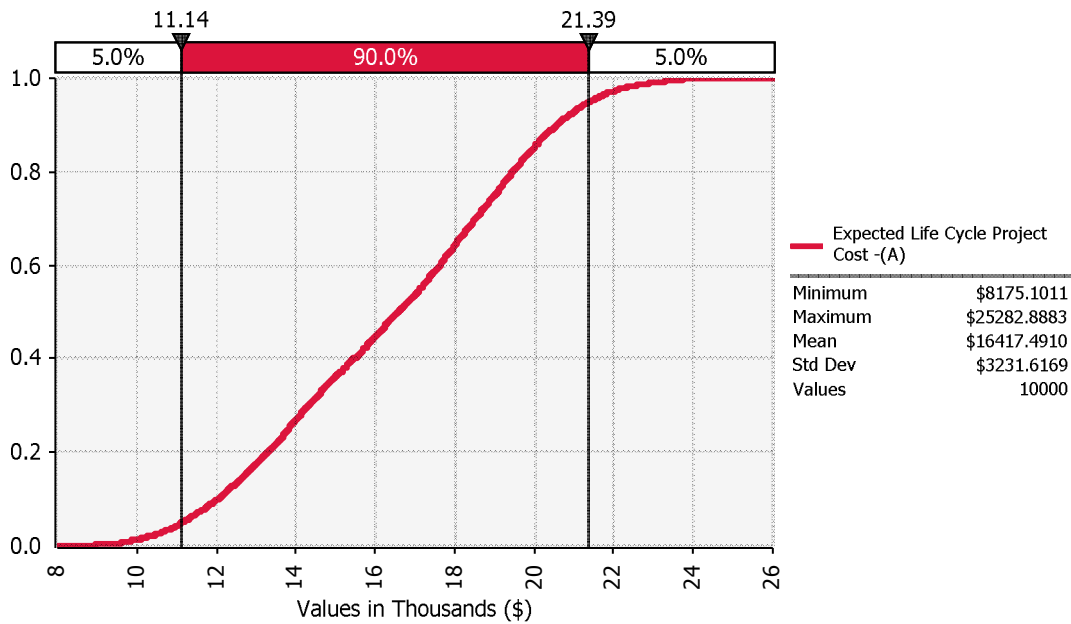


Figure 4. 5 Illustration of α risk profile for system A showing the Mean, Standard deviation, minimum and maximum values of the distribution.

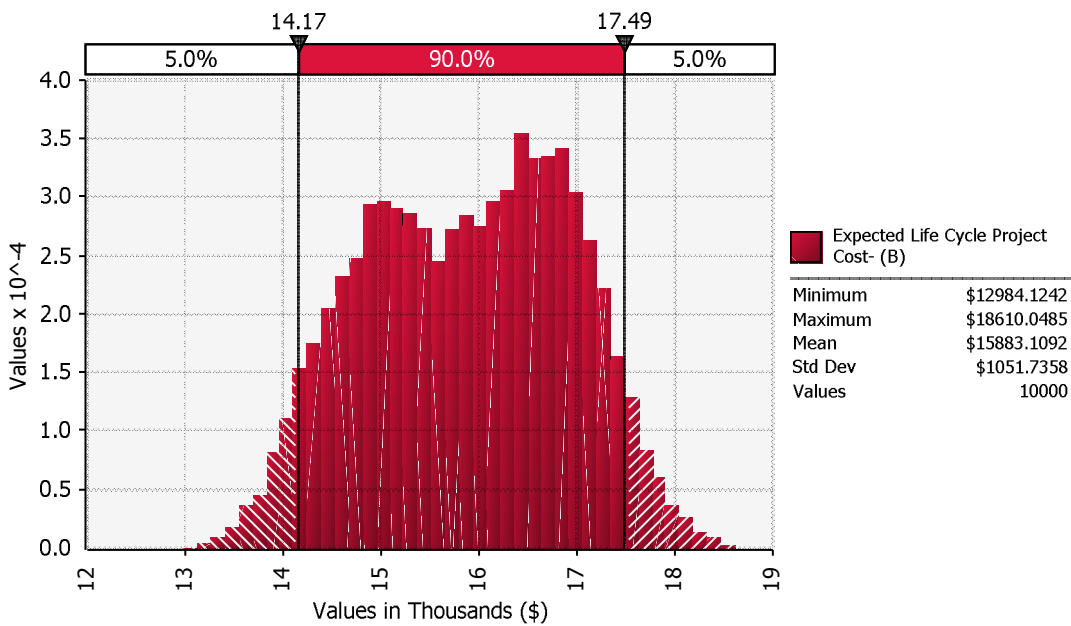


Figure 4. 6: Illustration of LCC histogram of system B

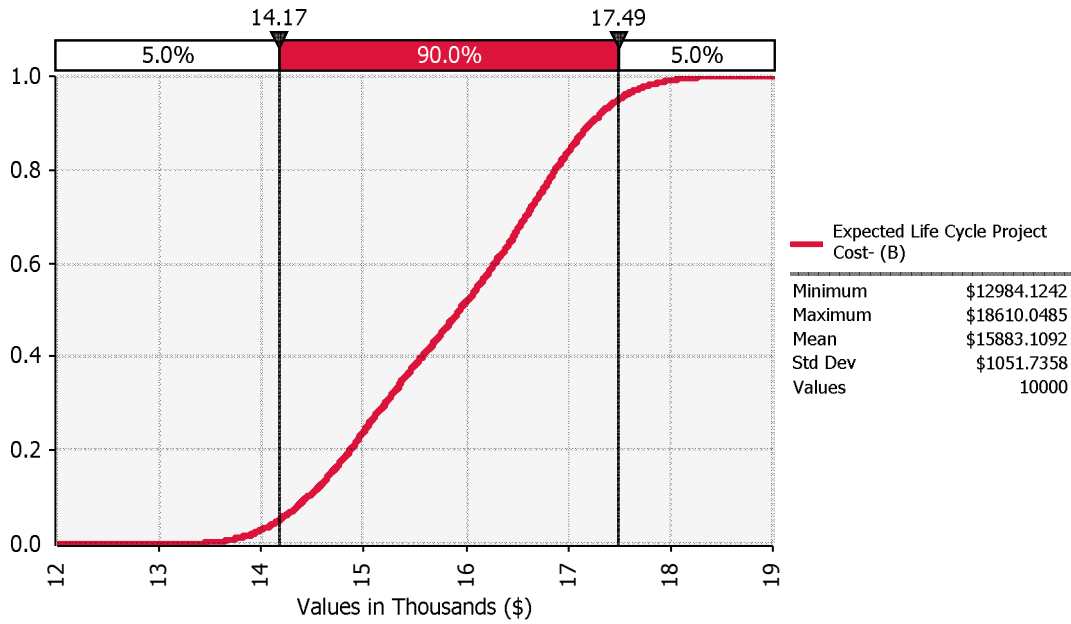


Figure 4. 7 Illustration of α risk profile of system B showing the Mean, Standard deviation, minimum and maximum values of the distribution.

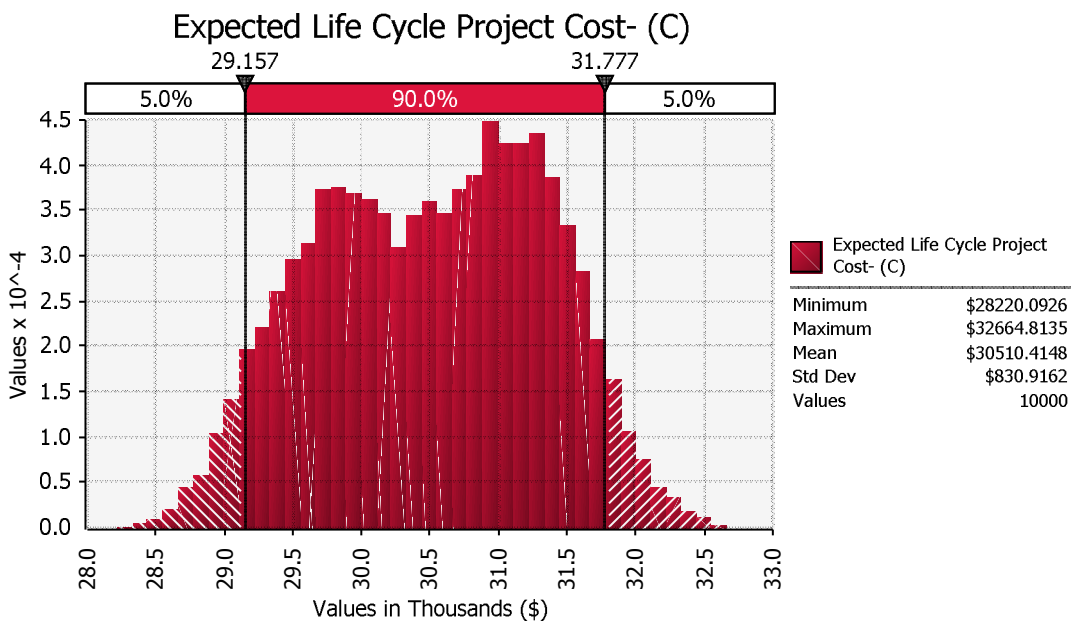


Figure 4. 8: Illustration of α histogram of system C

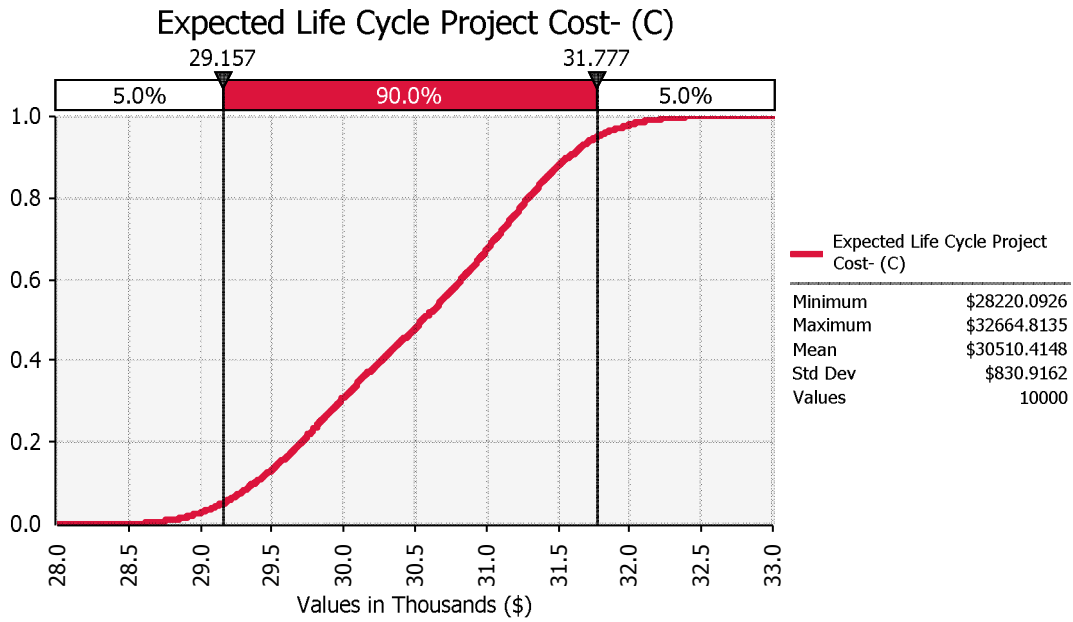


Figure 4. 9: Illustration of α risk profile of system C showing the Mean, Standard deviation, minimum and maximum values of the distribution.

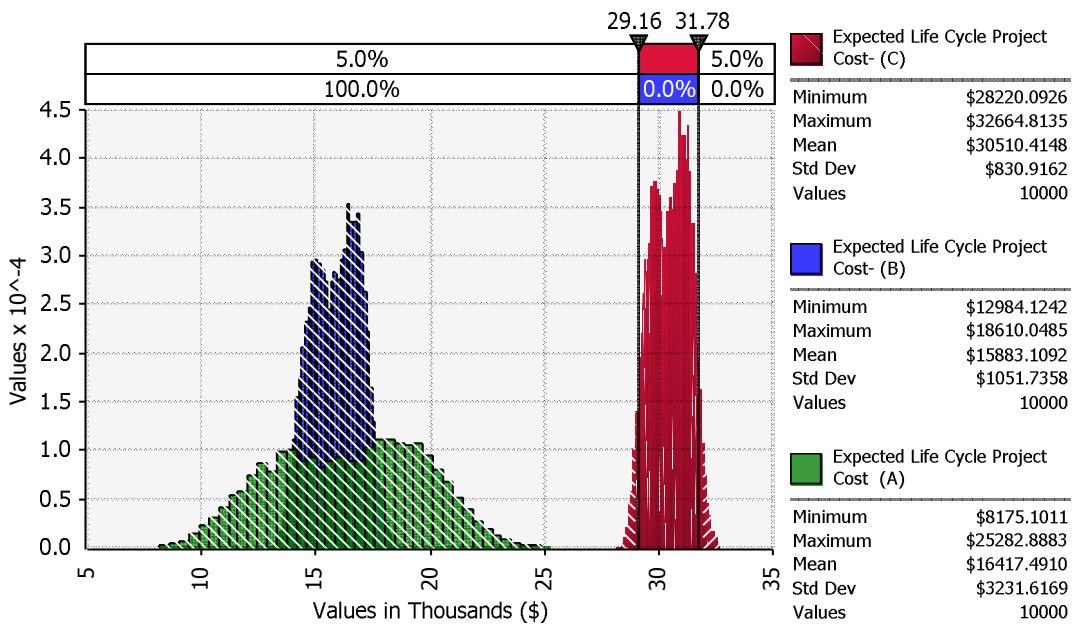


Figure 4. 10: Superimposed α histograms of systems A,B and C

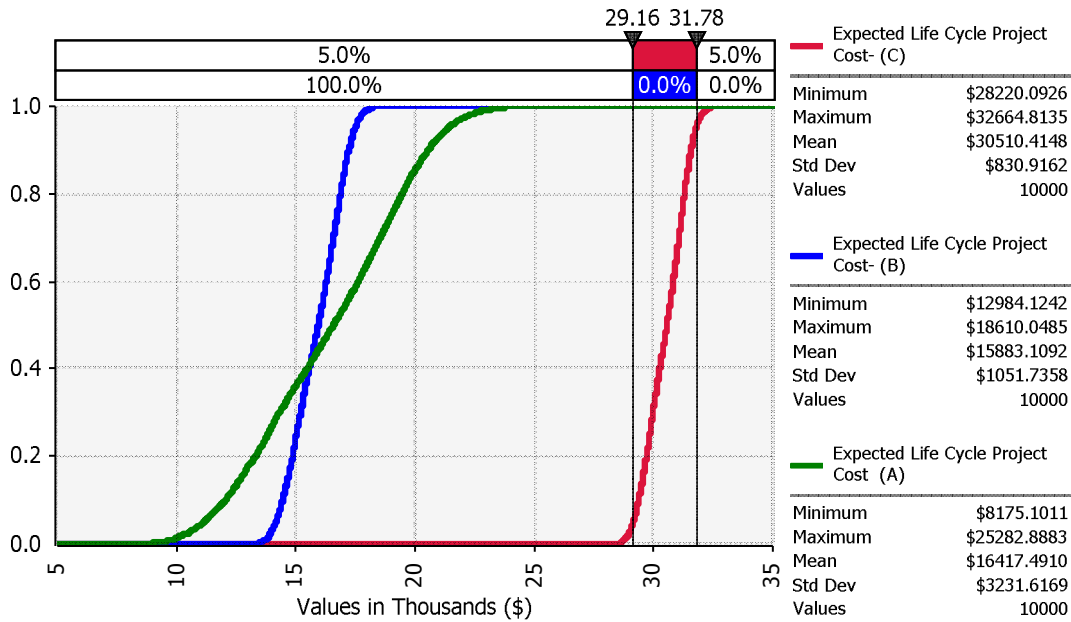


Figure 4. 11: Superimposed α risk profiles of system A,B and C

Sensitivity analysis

In order to further to chose between system A and B, the model was altered to force change at every chance node by eliminating the no-switch change (NS). This was done by simply altering the probabilities of scenario occurrences where the probability of NS scenario was reduced to zero while the probabilities for the other two remaining scenarios were change to fifty percent each. Figures 4.12 and 4.13 below show super imposed histograms and LCC risk profiles of system A, B and C. Based on evaluation of the LCC risk profiles, System C still stochastically dominates system B as its risk profile is completely to the right of B.

However this time there is no stochastic dominance between system A and the other two systems as the profile of system A crosses profiles of system B and C. But this time, spread of the profile of system A is very wide indicating that there is too much uncertainty that system A would perform well in the long run. The wide spread observed in the profile of system A will not instill confidence in an investor, but instead indicates much uncertainty in use of this system. Ultimately the decision maker will be compelled to select system B for this project.

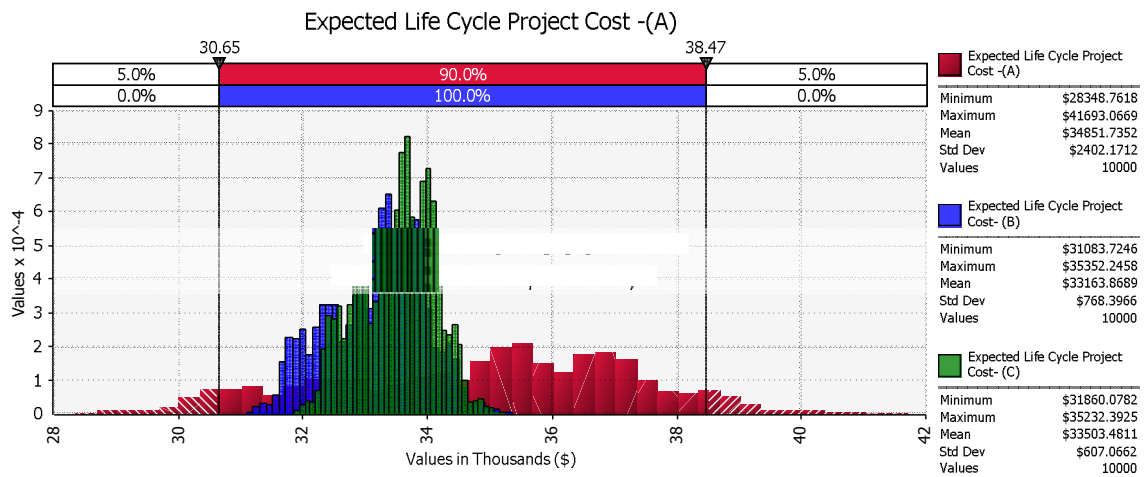


Figure 4.12: Superimposed α histograms for systems A, B and C under sensitivity analysis

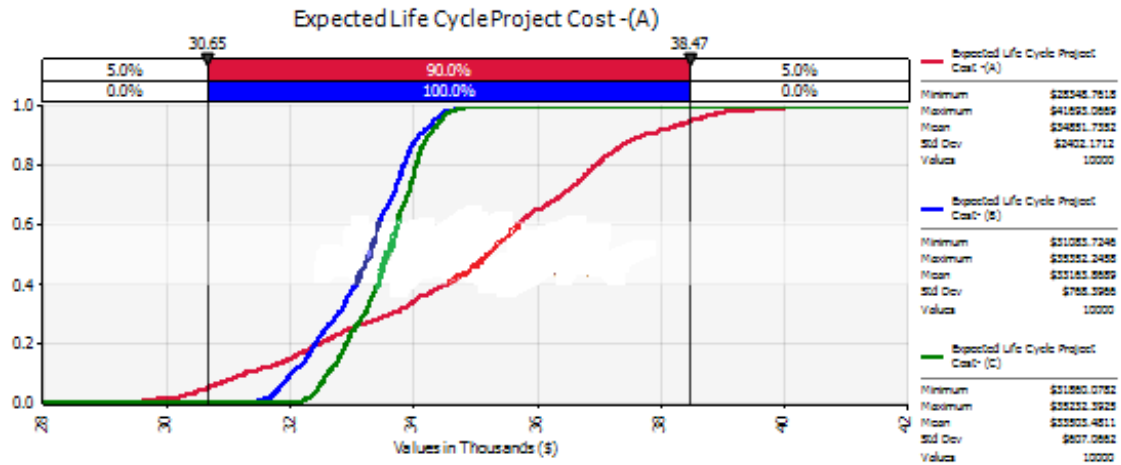


Figure 4.13: Superimposed α risk profiles for systems A, B, and C under sensitivity analysis

CHAPTER 5

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

Discussion and Conclusion

This thesis presents a new methodology for valuation of mutually exclusive partition systems under workspace uncertainty as a contribution to the existing body of knowledge in building construction and real estate. It advocates for use of risk profiles in value assessment of partition systems as opposed to absolute values that are determined through traditional life cycle cost methodology.

The new methodology respects the value of time by incorporating opportunity costs into the value analysis. The thesis' use of stochastic approach in forecasting project conditions allows time to become a unit of design analysis. This increases project risk management by anticipating change, providing ability to choose the most flexible and economically sensible alternative on the basis of stochastic dominance, expected value and variance. Unlike traditional life cycle cost analysis, this new methodology allows sensitivity analysis by allowing the decision maker to vary elements of the model such as costs and frequency of change to review the effects on results.

The methodology undoubtedly bridges existing gaps of knowledge discussed in the background: it provides a basis to use flexible partitions as advocated for in the rate of change theory to allow workspaces to evolve over time, it provides flexibility in workspace design to support Growth Strategy Alignment in CRE management, and it provides a

basis for selection of an alternative that can be used in RO application in workspace layouts.

Observations and Recommendations

The thesis presented a purely economical model that does not concern itself with assessment of the actual assembly of a partition system. Rather the presented model relies only on empirical data provided by cost data publications to conduct an analysis. It will be interesting to conduct further related research and evaluate flexibility of partitions from system assembly design perspective to determine ways of increasing flexibility in partition systems. It will also be interesting to explore the possibility of employing the principles of this new methodology in other building systems with the ultimate goal of exploring an integrated RO application in building design.

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